Validation of Land-Surface Temperature Retrieval from Space

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Abstract — We developed an integrated field TIR (thermal infrared) measurement system and methodology for validating land-surface temperature (LST) algorithms prepared for generating the EOS (Earth Observing System) MODIS (Moderate Resolution Imaging Spectroradiometer) LST product. The system has been used for measurements of spectral TIR BRDF (bidirectional reflectance distribution function) / emissivity and surface temperature of terrestrial materials in laboratory and field campaigns. Our validation results indicate that it is possible to validate LST within 1 °K in favorable atmospheric and surface conditions.

INTRODUCTION

Land-surface temperature (LST) is one of the key parameters in the physics of land-surface processes on a regional as well as global scale, combining the results of all surface-atmosphere interactions and energy fluxes between the atmosphere and the ground. Therefore it is required for a wide variety of climatic, hydrological, ecological and biogeochemical studies. In order to understand the entire Earth system better on the global scale, the Earth Observing System (EOS) will provide surface kinetic temperatures at specified accuracies of 0.3 °K for oceans and 1 °K over land.

MODIS (Moderate Resolution Imaging Spectroradiometer) is an EOS instrument that will serve as the keystone [1] for global studies of atmosphere, land, and ocean processes. It scans ±55° from nadir in 36 bands, with bands 1-19 and band 26 in the visible and near infrared range, and the remaining bands in the thermal infrared from 3 to 15 μm. It will provide images of daylight reflection and day/night emission of the Earth every 1-2 days, with continuous duty cycle. It uses 12 bits for quantization in all bands. The thermal infrared bands have an IFOV (instantaneous field-of-view) of about 1 km at nadir. MODIS will view cold space and a full-aperture blackbody before and after viewing the Earth scene in order to achieve calibration accuracy of better than 1% absolute for thermal infrared bands. MODIS is particularly useful because of its global coverage, radiometric resolution and dynamic ranges, and accurate calibration in multiple thermal infrared bands designed for retrievals of SST, LST and atmospheric properties.

Two LST algorithms have been developed for retrieving LST from MODIS data. The generalized split-window LST algorithm [2, 3] will be used to retrieve LST for surfaces with relative stable emissivities that can be referred from land cover types and a knowledge base of surface emissivities. A new physical based day/night LST method [4] will be used to simultaneously retrieve surface band-averaged emissivities and daytime and nighttime temperatures from day-night pairs of MODIS thermal infrared data. We have developed an integrated field TIR measurement system and methodology for validating these LST algorithms. Several field campaigns have been conducted and more validation activities have been planned.

VALIDATION OF MODIS LST ALGORITHMS

Overall Approach The validation is a comparison between temperatures retrieved from in-situ measurements and those retrieved from airborne and satellite thermal infrared data. Test sites such as silt playas and inland lakes have been chosen because their in-situ surface temperatures can be measured more accurately. These areas primarily validate the atmospheric correction and emissivity-extraction portions of the MODIS LST algorithms. We also plan to make in-situ measurements of surface temperature for validation over a wider variety of land cover types. After MODIS's launch these same techniques will be applied to validate the MODIS LST product.

Sampling Requirements Spectral requirements: spectral emissivities of land covers need to be measured in order to validate band-averaged surface emissivities. Spatial requirements: product validation needs to be carried out for different land cover types and different latitudes. This sampling should include a range of surface temperatures and atmospheric conditions. The land cover types will include prototypes of the main groups such as desert, bare soil, crop-land, grassland, forests, water, snow and ice. For unstructured surfaces, the in-situ measurements can be made with transects large enough to represent the aerial pixel average. For structured surfaces, tower or high-standing measurements will be required. Ideal test sites are in flat areas with size larger than 3km by 3km covered with uniform or uniformly mixed surface materials so that the uncertainty in spatial sampling could be significantly reduced. Temporal requirements: For in-situ measurements the short-term changes in temperature (in scale of seconds) are difficult to quantify, so weather conditions for such measurements must be stable (constant wind speed). In each validation field campaign, in-situ measurements will be made at least for a half hour to ensure the overpass of airborne and/or satellite flights is covered. LST need to be monitored monthly or each season throughout the year.

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The requirements for temporal sampling depend on latitude, and can be combined with the requirements for spatial sampling. In other words, we need a range of surface temperatures and atmospheric conditions. Angular requirements: The surface temperature algorithm should be validated over the range of MODIS look angles. Since there are more than one looks per day at high latitudes due to overlap and MAS (MODIS Airborne Simulator) views the Earth surface at different look angles, in-situ measurements should be made at multiple view angles at ground validation sites. For daytime measurements, a range of sun angles also must be incorporated for validation of the mid-infrared band processing and for validation of the mixed-temperature model with structured surfaces.

Measures of Success The metric for measures of success will be the difference between the surface temperature from in-situ measurement data and that retrieved from airborne or satellite data. Since there are errors in both the ground measurements and the aerial measurements, the success criterion will depend on the ground measurement accuracy as well as the accuracy of airborne and satellite data. All major components of the instrument used in ground measurements should be carefully calibrated. The success criterion will also depend on atmospheric and surface conditions. It is critical to have high quality ground measurements data with smooth temporal and spatial variations in order to reduce the uncertainties in temporal interpolation, spatial sampling, and geometric co-registration. Records of the atmospheric and surface weather conditions, analysis of temporal and spatial variations should be provided with the difference between LST values from in-situ measurements and those retrieved from airborne and satellite data for each field campaigns. The LST product will be considered valid when the standard deviation of LST differences is smaller than or around 1 °K and the uncertainties in instrument calibrations, temporal and spatial variations are well below 1 °K.

Instrumentation and Methodology Surface temperature measurements can be made with contact sensors, hand-held infrared thermometers as wideband radiometers, and infrared spectrometers. Transects will be made with infrared thermometers. The contact sensors are primarily for water surface temperature measurements. The spectrometers do not translate easily, but they can scan a range of angles to provide temporal and angular spectral surface radiance and atmospheric downwelling radiance (from a diffuse reflector). Temperature is recovered directly from the contact sensors. The downwelling radiance, instrument calibrations, and surface emissivity must be applied to compute the temperature from the non-contact sensors. Spectral directional-hemispherical emissivity can be measured with an integrating sphere facility which includes a Fourier transform infrared (FTIR) spectrometer and a 5-inch infragold integrating sphere. The spectrometer has sensitivity both in the mid and thermal infrared, covering all MODIS bands of interest for LST. This instrument is primarily used for emissivity measurements of samples such as ice, water, silt, sand, soil, leaf surface, etc. The surface roughness of these samples is limited to a few millimeters. Field measurements of BRDF (bidirectional reflectance distribution function) / emissivity are made with the SIBRE (Spectral Infrared Bidirectional Reflectance and Emissivity) instrument, which includes a hemispherical pointing system, FTIR spectrometer, a TIR source, and reference plates. The effect of surface temperature change due to the thermal source heating is carefully corrected [5]. Samples of approximately one square foot are measured with 187 source-sensor geometries. An abbreviated measurement set of 45 geometries is an alternative for materials whose BRDF shapes are reasonably well known. For each geometry, there are 1232 spectral samples from 3.3 to 14.5 microns. These can be integrated to provide band-averaged values for MODIS or MAS. The spot size viewed by the InSb/MCT sandwich detector is approximately 3cm diameter so materials with some small-scale surface structure can be examined. We also have a beam expander that gives a 10cm spot for more structured surfaces. We can recover angular spectral emissivity (but not BRDF) from absolute radiance measurements using a sun-shadow technique. Our goal for the sun-shadow method is to increase the spot size to an half meter so that band-averaged emissivities and radiometric temperature of structured surfaces such as vegetation canopy can be measured.

Some Validation Results We validated the sun-shadow method with measuring samples of soil, sands, grass and a black aluminum plate on the roof platform of our building at UCSB on January 19th and 26th, 1996. The solar beam is blocked for an half of the samples. The TIR spectrometer views the portions in sunshine and in shadow for two separate measurements and also views a diffuse reflecting gold plate in the same spots for providing information of the solar and atmospheric downwelling radiation. After calibrating the spectrometer with blackbody at three different temperatures, another two separate measurements are made. For each sample, we obtained two pairs of data for the sunshine and shadow portions and the diffuse reflecting gold plate. A band average procedure with the spectral response functions in 7 MODIS TIR bands (i.e., 20, 22, 23, 29, 31, 32, and 33) is used to achieve a high signal-to-noise ratio. Radiometric calibration is made with 3 blackbody temperatures, spectral emissivity of the blackbody surface and the front mirror, and the temperature of the front mirror. Then we use two methods to recover the surface temperature. In the conventional method, we use the spectral emissivity curves of samples measured with the integrating sphere system. In the sun-shadow method, we make non-linear χ^2 fit of the sun-shadow data set for recovering surface temperatures in sunshine and in shadow, and the band-averaged emissivities. The LST values of samples of sand, soil, grass and black plate in sunshine and in shadow recovered by these two methods are shown in Fig. 1. Noted that the mark squares represent the first method. The standard deviations are 0.4 °K and 0.1 °K, and the maximum LST differences are 0.7 °K and 0.2 °K, for the LST difference in sunshine and in shadow, respectively.

We conducted a field campaign with the JPL (Jet Propulsion Laboratory) ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) team at a large flat silt playa site in Railroad Valley, Nevada, on August 3rd, 1995. MAS and TIMS (Thermal Imaging Multispectral Spectrometer) data, and field measurement data of surface spectral emissivity and temperature with TIR spectrometer and broadband radiometer were collected. Temporal and spatial analysis has been made. As shown in Table I, LST retrieved from MAS data using the generalized split-window LST algorithm at view angle (θ_v) 18.95° agrees with field measurement LST values within 1 °K. In this case, the LST accuracy is mainly limited by the uncertainty in its spatial variation. The MAS was calibrated with the new method [6].

CONCLUSION

We developed an integrated field TIR measurement system and methodology for validating MODIS LST algorithms. Our validation results indicate that it is possible to validate LST within 1 °K in favorable atmospheric and surface conditions.

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Table I. Summary of LST values over the test site (38' 31.46'N, 115' 42.74'W) in Railroad Valley, NV during 1:22 and 1:30 PDT on 8/3/95.

size of area	mean (°K)	stdv (°K)	remarks
12 cm diameter	58.5		by radiometer
5 cm diameter	59.2		by spectrometer
1 MAS pixel	59.1		at θ_v 18.75°
3 by 3 MAS pixels	58.9	0.48	
5 by 5 MAS pixels	58.8	0.67	
7 by 7 MAS pixels	58.9	0.76	
9 by 9 MAS pixels	59.0	0.81	
11 by 11 MAS pixels	58.9	0.82	
21 by 21 MAS pixels	58.9	1.21	

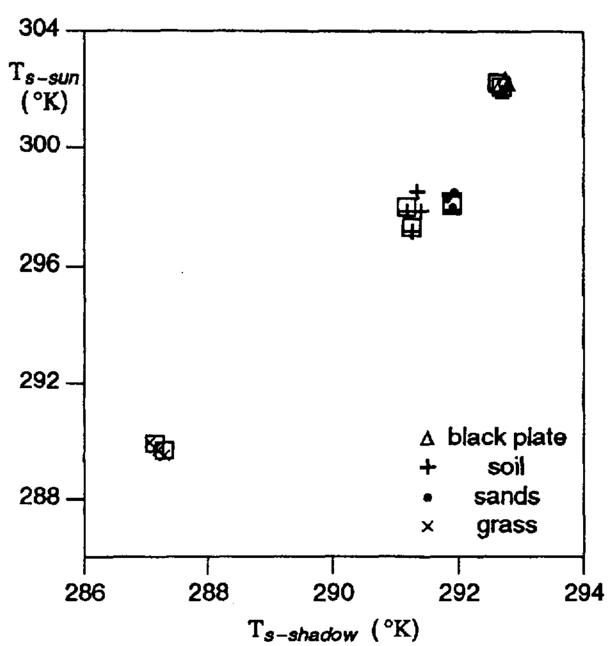

Fig. 1, LST values retrieved by using two methods.